Biological & Medical Serials

November 1916. Chemical Series. Vol. V. No. I.

Memoirs of the Department of Agriculture in India

STORAGE

THE GASES OF SWAMP RICE SOILS

PART IV
THE SOURCE OF THE GASEOUS SOIL NITROGEN

THE ROYAL CANADIAN INSTITUTE

BY

W. H. HARRISON, D.Sc

Government Agricultural Chemist, Madras

AND

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Assistant to the Government Agricultural Chemist

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PRINTED AND PUBLISHED FOR

THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY

THACKER, SPINK & CO., CALCUTTA

W. THACKER & CO., 2 CREED LANE, LONDON

Price, Rs. 2 or 3s. 6d.

Edited by

The Council of the Pusa Agricultural Research Institute.

November, 1916. CHEMICAL SERIES. VOL. V, No. 1.

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[Received for publication on 31st January, 1916.]

Introduction.

In a recent publication,[1] it was shown that considerable quantities of nitrogen gas were formed in swamp rice soils and that there were certain peculiar relationships between the incidence of this gas and the crop and green manure used which required elucidation.

The gas found in these soils is mainly a mixture of methane and nitrogen, but the proportion these gases bear to each other varies considerably with, and is dependent upon, several well defined factors. In uncropped soils, whether manured or unmanured, the methane greatly preponderates throughout the whole cultivation season. This also applies to cropped soils during the earlier period of growth, but about thirty days after the date of transplanting a rapid change sets in and the nitrogen becomes the preponderating constituent, and this relationship persists up to harvest time.[2] Consequently, the composition of the soil gases is modified by the presence or absence of a crop.

Furthermore, it was shown that there is more gas present in cropped than in uncropped soils,[3] which means a considerably increased production of

[1] Harrison and Subramania. The Gases of Swamp Rice Soils. Part I, Their composition and relationship to the crop. *Mem., Dept. Agri., India, Chem. Ser.*, vol. III, no. 3.

[2] *Ibid*, pp. 69-74.

[3] *Ibid*, p. 81.

nitrogen gas when the difference in composition of the gas is taken into consideration. In addition, it was found that the evolution of nitrogen was greatly influenced by the presence of green manure for there is approximately $2\frac{1}{2}$ times as much gas present in manured soils as in unmanured soils.[1] From this it follows that the production of nitrogen gas in swamp rice soils is mainly determined by two factors, one being the crop itself and the other the organic matter present in the soil and the green manure used.

These facts led to the tentative conclusion that in these soils there occurs a liberation of nitrogen gas from organic manures, which are therefore to this extent made of no direct agricultural value. This conclusion, although based upon field observations, is of dubious value, because the facts upon which it is formed deal only with the gases actually present in the soil at any particular time, for there must be a considerable escape of gas from these soils, and this may vary considerably under different conditions and be of such dimensions as to materially alter, if not even reverse, the above conclusion. It is obvious that this last factor must be evaluated if valid conclusions relating to the source of the nitrogen gas are to be drawn.

An attempt was made to measure the dimension of this factor under field conditions by inverting a large funnel filled with water over the surface of the soil, so as to trap any escaping gas.[2] Large volumes of gas were collected but as it was a mixture of oxygen and nitrogen, instead of methane and nitrogen, it was obvious that it had little, if any, connection with the soil gases proper. The source of the gas thus collected was traced to an organized film covering the surface of the soil which has been shown to possess the power of decomposing any carbon dioxide present in the irrigation water with the evolution of oxygen, and also to oxidize any methane and hydrogen as they escape from the soil to carbon dioxide and water. The carbon dioxide thus produced is in turn decomposed with the evolution of oxygen.[3] The nitrogen found associated with the oxygen thus evolved from the surface of the soil appears to be derived by diffusion from the nitrogen dissolved in the irrigation water.

This being the case, any attempt to measure the volume of the nitrogen escaping from the soil is doomed to failure so long as this surface film is operative. Copper sulphate added to the irrigation water was found to kill, or render inoperative, the organisms composing the film, but great difficulties presented themselves when applied on the field scale. As an alternative

[1] *Ibid*, p. 81.

[2] *Ibid*, p. 75.

[3] Harrison and Subramania. The Gases of Swamp Rice Soils. Part II, *Mem., Dept. Agri., India, Chem. Ser.*, vol. IV, no. 1.

potculture experiments were instituted[1] in which a very dilute solution of copper sulphate was used as irrigation water. This was found to greatly reduce the activity of the film and it was found possible to obtain some measurements of the volumes of the escaping gases under varying conditions of experiments which are detailed in the memoir previously referred to.

Experience has shown that these first experiments were of an unsatisfactory character but they brought out certain important facts which have since been confirmed. In the first place they distinctly showed that the escape of gas from uncropped soils was fairly uniform, whereas the amount escaping from cropped soils is practically *nil* until the crop reaches the heading stage, when a considerable evolution of gas occurs which continues up to harvest time. This was tentatively ascribed to the crop influencing the normal course of the soil fermentations. In the second place indications were obtained showing that more nitrogen was evolved from manured than from unmanured soils.

Notwithstanding this, it was felt that the evidence obtained was far from being satisfactory. In fact, in several respects, it materially conflicted with the deductions drawn from field observations, and consequently, these experiments have been continued under more rigorous and varied conditions. They have yielded results from which definite conclusions may be drawn and which offer an explanation of many of the peculiar facts previously noted which have hitherto remained unexplained.

One reason for the inconclusive results of the earlier experiments was due to the fact that the measurements and analyses were stopped immediately the ripening stage was reached and this limited the number and the scope of the observations. This error has been rectified and the records now given are carried up to the time of harvesting.

The most serious error, however, introduced into the earlier experiments was due to the action of the film in bringing about an evolution of nitrogen gas derived directly from the irrigation water and indirectly from the air. This action of the film is inhibited by the use of copper sulphate in the irrigation water, and this inhibition continues so long as soluble copper salts are present, but immediately this condition fails, owing to the precipitation of the copper, the activity of the film recommences and nitrogen, not derived from the soil, is evolved. In the earlier experiments the addition of copper sulphate was carried out, as was only natural, in a cautious manner and at long intervals, so that occasionally the film became active again leading to an increased evolution of nitrogen. Thus in one experiment a pot was yielding 0·07 cc.

[1] *ibid*, Part I.

of oxygen and 0·3 cc. of nitrogen per day when it suddenly began to yield 3·6 cc. oxygen and 38·6 cc. nitrogen. On adding a further quantity of copper sulphate the evolution diminished to 0·3 cc. oxygen and 7·5 cc. nitrogen.

As any attempt therefore to measure the nitrogen evolution from the soil proper depends for its success upon the film being rendered inoperative throughout the whole course of the experiment, a stronger solution of copper sulphate has been used in the experiments to be described, and it has been given at more frequent intervals. So far as could be observed the increased dose had no harmful effect on the crop, but rather the reverse, for experiments instituted to test this point showed the copper to act as a crop stimulant.

There is no great difficulty experienced in controlling the action of the film in uncropped pots for any failure in this respect is at once made apparent by a greatly increased output of gas containing a considerable proportion of oxygen. In the case of cropped pots, however, difficulties present themselves for the oxygen formed by the film is absorbed by the roots, and the only result of the failure is to lead to an increased collection of nitrogen. In fact, in cropped pots it is possible for the film to be in an active condition without the fact being readily detected, and it is to this that the inconclusive results of our earlier experiments must be ascribed.

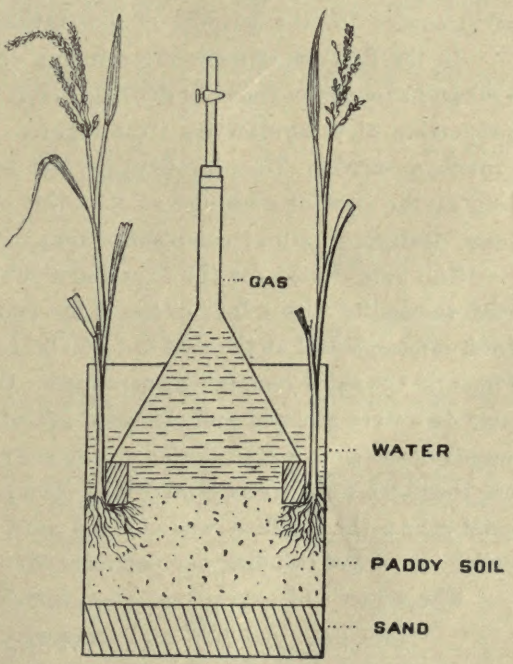
In the experiments now to be described particular attention was paid to the maintenance of a supply of copper sulphate in the surface water sufficient to inhibit the action of the film, and only by rigorously attending to this point has it been found possible to obtain concordant results. The experimental difficulties are enhanced by the fact that the surface water can only be conveniently changed at the time when the gases which have collected are removed for examination, so that the concentration of copper sulphate needs to be considerable in order to attain the desired result.

In all the experiments no drainage was arranged for with the object of limiting the amount of copper sulphate entering the soil to that drawn in under the action of transpiration, and possibly also a small amount by diffusion, so as to reduce to a minimum the danger of this substance affecting the normal soil fermentation. Concentrations varying from $\frac{1}{250,000}$ to $\frac{1}{5,000}$ have been used without in any way modifying the type of result obtained, and it therefore seems permissible to conclude that the amount which enters the soil under the experimental conditions does not materially affect the normal course of events in the soil.

Notwithstanding these precautions, it is impossible to eliminate all traces of oxygen from the gases obtained, owing to the fact that they are collected

over water which, outside the funnel, is exposed to the air, and consequently, some diffusion must always occur. The amount thus diffusing can, however, be reduced to negligible proportions by using funnels for the collection of the gas of such a size that there is only just space enough between the edge of the funnel and the side of the pot for the growth of the seedlings. In these circumstances the surface of water exposed to the air is reduced to a minimum and the amount of oxygen which diffuses is consequently very small. When these conditions are fully satisfied the accumulation of oxygen is only from 0·05 to 0·2 cc. per day, and this amount may be looked upon as constituting a constant error for all the pots and be eliminated from further consideration. For this reason the oxygen values are not given in the sequel as they would serve no useful purpose and would unduly complicate the tables.

Apart from these considerations, the method of carrying out these experiments does not materially differ from that previously adopted by us. As all the experiments to be considered were carried out in a similar manner it will be as well to describe the method at this stage in order to prevent unnecessary repetition later.



The pots selected for the experiments were filled with the soil used to within about four inches from the brim. To those pots which were to receive manure the calculated amount was added and then all the pots were well puddled, distilled water being used for this purpose. In each pot four small wooden blocks were pushed into the soil to such a depth that they would support a funnel just clear of the surface of the soil. The seedlings were then planted around the circumference of such pots as were intended to carry a crop, care being taken to maintain the same number in each pot, and when they were firmly established copper sulphate solution was gently poured on the surface of the soil until the pot was filled with the solution. The funnels, provided with good stopcocks in the shanks, were now placed in position and

filled by removing the air by suction. Thus any gas which subsequently escapes from the soil collects in the funnel from which it can be drawn and analysed at convenient intervals.

The experiments now under consideration have been carried out under very varying conditions and have extended over several seasons. Variation of soil, different varieties of paddy, mixtures of sand and soil, and even sand alone have been used. Each series of experiments has thrown considerable light on the immediate problem under consideration, but it is only by considering the results as a whole that definite conclusions can be drawn. Each type of experiment, however, serves to emphasize certain facts so that they will be considered individually in the first instance.

Experiments with Paddy Soil.

During the course of the past three years a large number of distinct pot-culture experiments have been carried out with paddy soils which have all yielded results of a very similar character and have led to the same general conclusions. This being the case, the results of two typical experiments only are recorded for the purpose of illustration.

In the first experiment the soil was obtained from a paddy field of the College Farm at the time of puddling, and it therefore contained a considerable proportion of comparatively fresh organic matter derived from the surface growth of weeds. This, however, is the natural condition of swamp paddy soils at the time of puddling so that this experiment probably approximates most nearly to natural conditions of any carried out.

The pots chosen for the experiment were of uniform size and were filled with the soil to within four inches of the rim. Three pots were manured with fresh *calotropis* leaf at the rate of 5,000 lb. to the acre, two being placed under crop and the third remaining uncropped. Of three corresponding unmanured pots two were cropped and the third left uncropped. After being thoroughly puddled the pots were allowed to remain untouched for seven days and then the seedlings were transplanted into them. When the seedlings were firmly established the surface was covered with copper sulphate solution and the collection of the escaping gas commenced. The paddy was a long-date type.

The scheme of experiment was, therefore, as follows :—

Two pots manured and cropped.
One pot manured but uncropped.
Two pots unmanured and cropped.
One pot unmanured and uncropped.

The results obtained are set out in Table I.

TABLE I.

Showing the evolution of Methane and Nitrogen from fresh soil.

cc. N. T. and P.

MANURED POTS.

Days collecting gas	Cropped Pot I				Cropped Pot II				Uncropped Pot				Remarks
	Nitrogen		*Methane*		*Nitrogen*		*Methane*		*Nitrogen*		*Methane*		
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	
1st to 30th day ...	23·2	0·77	nil	nil	4·5	0·15	nil	nil	6·9	0·23	nil	nil	
30th to 59th ,, ...	2·0	0·07	nil	nil	5·5	0·19	nil	nil	56·4	1·94	0·9	0·03	
59th to 93rd ,, ...	1·9	0·06	nil	nil	5·9	0·17	nil	nil	34·0	1·00	1·5	0·04	
93rd to 110th ,, ...	33·8	1·99	5·1	0·30	37·8	2·22	5·6	0·33	13·7	0·80	1·8	0·10	Heading commenced about the 100th day.
110th to 117th ,, ...	32·4	4·63	7·8	1·11	53·6	7·66	8·8	1·25	4·8	0·69	0·7	0·10	
117th to 124th ,, ...	22·1	3·16	6·8	0·97	30·6	4·37	9·7	1·38	5·6	0·40	nil	nil	
124th to 131st ,, ...	25·5	3·64	7·9	1·13	26·5	3·79	10·5	1·50					
131st to 142nd ,, ...	52·3	4·75	14·5	1·32	54·3	4·93	18·6	1·69	13·0	0·60	0·8	0·03	
142nd to 153rd ,, ...	25·5	2·32	5·5	0·50	32·3	2·93	8·0	0·73					
Totals and averages ...	218·7	1·42	47·6	0·31	251·0	1·64	61·2	0·40	134·4	0·88	5·7	0·04	

UNMANURED POTS.

1st to 31st day ...	8·0	0·26	nil	nil	6·3	0·20	nil	nil	17·7	0·57	nil	nil	
31st to 60th ,, ...	3·6	0·12	nil	nil	2·0	0·07	nil	nil	46·1	1·59	nil	nil	
60th to 94th ,, ...	3·8	0·11	nil	nil	2·1	0·06	nil	nil	27·5	0·81	nil	nil	
94th to 111th ,, ...	6·2	0·36	0·9	0·05	5·5	0·32	0·9	0·05	5·3	0·31	nil	nil	
111th to 119th ,, ...	6·8	0·85	0·5	0·06	10·6	1·32	0·6	0·07	2·4	0·30	0·8	0·01	Heading commenced about the 100th day.
119th to 133rd ,, ...	22·0	1·57	4·3	0·30	26·0	1·86	3·1	0·22					
133rd to 143rd ,, ...	22·5	2·25	3·5	0·35	13·2	1·32	1·4	0·14	5·9	0·12	nil	nil	
143rd to 159th ,, ...	15·6	0·97	2·4	0·15	9·0	0·56	0·6	0·04					
Totals and averages ...	88·5	0·56	11·6	0·07	74·7	0·47	6·6	0·04	104·9	0·66	0·8	...	

A consideration of these results from the general point of view shows, with regard to the manured pots, a much greater total evolution of nitrogen from cropped than from uncropped pots. At the same time the volume is greater from all the manured pots than from the corresponding unmanured pots. On the other hand, the volume given off from cropped unmanured pots is less than that from the corresponding uncropped pots. It is evident, therefore, that two of the deciding factors regulating the production of nitrogen gas, are the presence or absence of a crop and the amount of organic matter in the soil.

The most interesting conclusions to be drawn are, however, not those made between total volumes evolved, but those which emerge when the results are examined in detail. In Chart I, the numerical values obtained are plotted out in the form of addition curves showing the total amount of nitrogen evolved up to any particular date. A study of these curves shows that in uncropped pots the nitrogen evolution is most pronounced in the early stages, whereas, in cropped pots the reverse holds good, there being very little gas given off until the growing season is well advanced. It is further evident that this difference holds good whether the pots are manured or not, the manure, however, greatly affects the magnitude of the result. These relationships are perhaps brought out in a clearer manner in Chart II where the variations in the rates of evolution are plotted out as curves.

The main conclusions brought out by the above comparisons are :— (1) *that the sequence of events is similar both in manured and unmanured soils and the only factor which affects the type of result obtained is the presence or absence of a crop in the soil*, and (2) *that the presence of green manure only affects the results in a quantitative manner, larger volumes of gas being then evolved.*

If the very probable assumption is made that the type of result obtained in uncropped pots represents the normal decomposition of organic matter in these soils, it becomes necessary to account for the action of the crop in (*a*) retarding the normal rate of nitrogen evolution in the earlier stages of growth, (*b*) in accelerating the normal rate in the later stages, and (*c*) causing an increased evolution of nitrogen in cropped manured soils compared with uncropped manured soils, whereas, the reverse is the case in unmanured soils. As the type of result is the same in cropped soils whether they are manured or not it would seem probable that the solution of the problems (*a*) and (*b*) would also offer a solution for (*c*).

One distinct fact is brought out by the experiments, namely, that in the early stages of growth comparatively little gas escapes from cropped soils compared to a fairly uniform evolution from uncropped ones. On the other hand, at about the time when the crop commences to run up for flowering

CHART I. Showing total evolution of Nitrogen to date from Paddy soils.

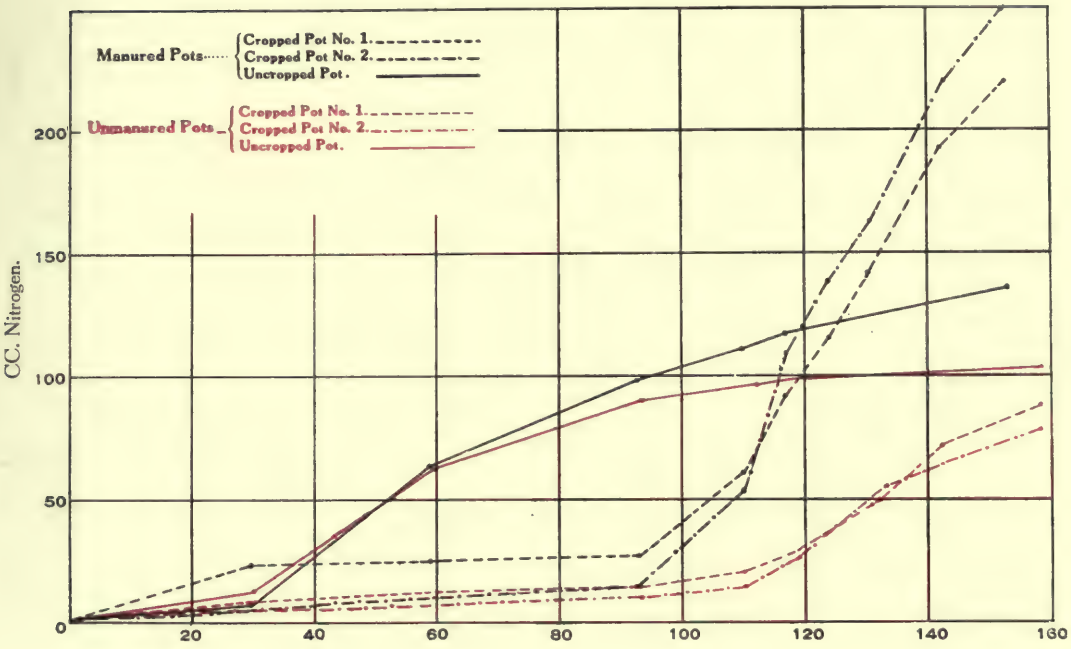


CHART II. Showing variations in rate of Nitrogen evolution from Paddy soil.

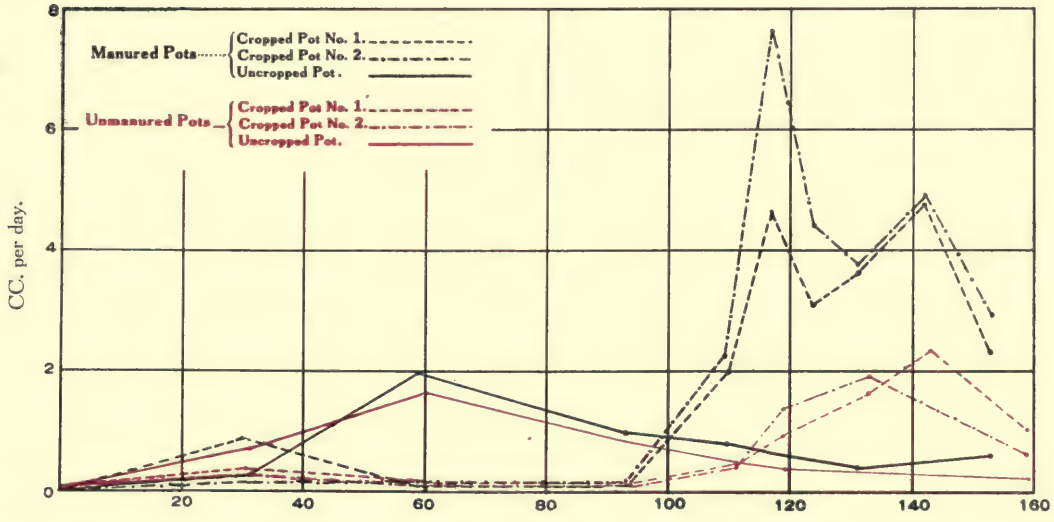


CHART III. Showing total evolution of Nitrogen to date from stored Paddy soil.

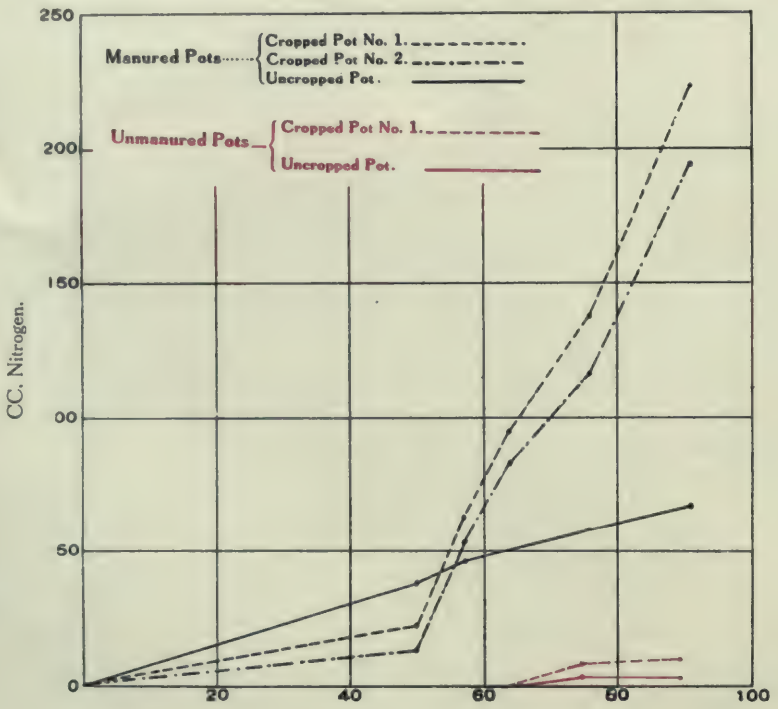
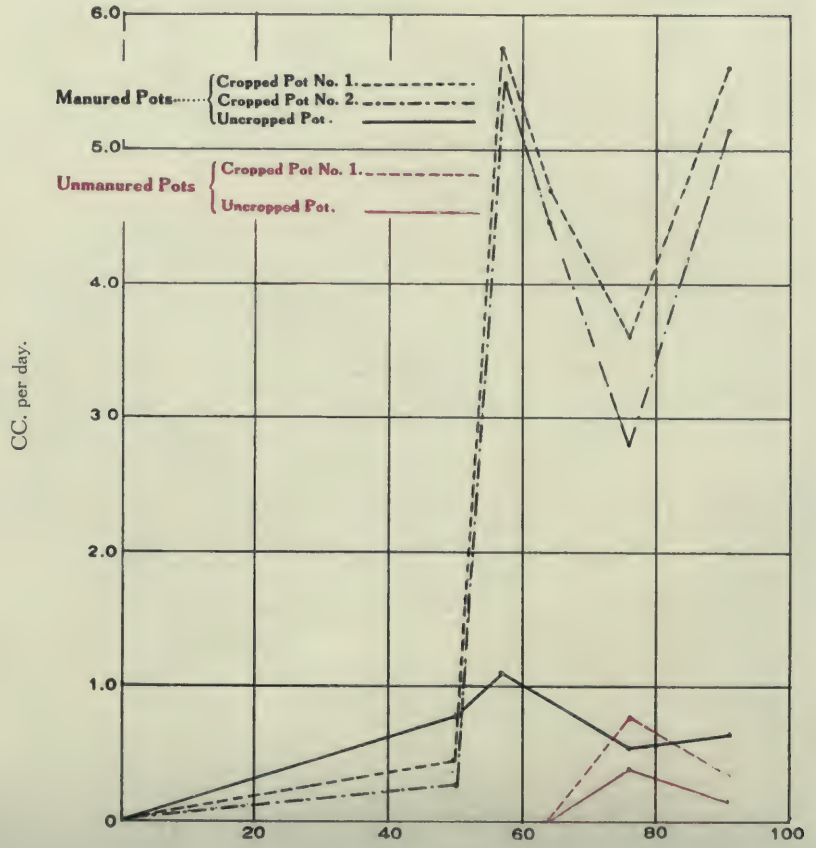


CHART IV. Showing variations in rates of Nitrogen evolution in stored soils.



there is a sudden and very considerable disengagement of gas which continues to harvest time, whereas, there is no such outburst in uncropped soils. This sudden evolution of nitrogen is accompanied by a similar disengagement of methane, so that it is justifiable to assume that the phenomenon is connected with the decomposition of organic matter.

In this experiment the volume of nitrogen given off by the uncropped unmanured pot is very nearly equal to that from the corresponding manured pot. In these uncropped pots, none of the nitrogen can be derived from the atmosphere through the agency of drainage, transpiration of a crop, or the activity of the surface film, and it is permissible to assume that its source is that of the organic matter contained in the soil. The particular soil used in this experiment was obtained from a paddy field at the time of puddling and contained a considerable proportion of vegetable detritus derived from the roots and debris of the preceding crop, and also the weeds and grasses raised during the dry season, so that the proportion of green manure added would only slightly increase the amount of organic nitrogen in the soil of the manured pot, and the volume of nitrogen evolved would not be greatly different from that of an unmanured pot, as is the case in this experiment.

If by any suitable means the proportion of decomposable organic matter in the soil could be greatly reduced, it would appear probable that comparatively little gas would be given off from unmanured soils and a greater differentiation produced in the experimental data which should result in making more prominent the effect of the crop and the manure. It was, therefore, decided to repeat the former experiment under conditions approximating to the above.

The immediate problem was to eliminate the easily decomposable organic matter from the soil without unduly affecting the biological and physical conditions. Burning the soil was out of the question as this would destroy all bacterial life and thus probably alter the normal course of fermentation. After considering the problem it was thought that the object aimed at could approximately be attained by storing the soil for some months before carrying out the experiment for, at tropical temperatures, organic matter of this type is quickly humified and brought into a comparatively stable state. This would also have the advantage of retaining sufficient nitrogen in the soil to feed the crop in the unmanured pot.

With the exception of using this stored soil instead of fresh soil and of using pure seed of a short date paddy strain, kindly supplied by Mr. Parnell, the Government Economic Botanist, the conditions of experiment remained the same as in the one just considered. The results of this experiment are given in Table II and the corresponding curves in Charts III and IV.

TABLE II.

Showing the evolution of Nitrogen from stored soil.

cc. N. T. and P.

MANURED POTS.

Days collecting gas	CROPPED POT I				CROPPED POT II				UNCROPPED POT			
	Nitrogen		*Methane*		*Nitrogen*		*Methane*		*Nitrogen*		*Methane*	
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate
1st to 50th day ...	22·7	0·45	5·8	0·12	13·9	0·28	3 7	0·07	39·1	0·78	nil	nil
50th to 57th ,, ..	40·2	5·74	18·3	2·61	38·4	5·49	16·4	2·34	7·8	1·11	nil	nil
57th to 64th ,, ...	32·9	4·70	17·1	2·44	31·0	4·43	11·9	1·70	10·9	0·57	nil	nil
64th to 76th ,, ...	43·0	3·58	22·9	1·91	33·5	2·79	9·6	0·80				
76th to 91st ,, ...	84·3	5·62	28·9	1·92	77·4	5·16	16·7	1·11	9·6	0·64	0·5	0·03
Totals and averages ...	223·1	2·45	93·0	1·02	194·2	2·13	58·3	0·64	67·4	0·74	0·5	...

UNMANURED POTS.

1st to 64th day ...	nil	nil	nil	nil	...	...	...	...	nil	nil	nil	nil
64th to 76th ,, ...	9·7	0·81	...	...		...	...	...	5·4	0·40		...
76th to 91st ,, ...	4·9	0·33	...	...	...	...	..	...	2·1	0·14	...	...
Totals and averages ...	14·6	.	.	...		...	...	...	7·5	...	..	...

This experiment shows that, so far as the manured pots are concerned, the reduction of the amount of decomposable organic matter had no effect upon the type of result obtained. There is still a very much larger evolution of nitrogen from the cropped pots than from the uncropped ones, but as in the previous experiment the greatest rate of evolution with the cropped pots is attained after the heading stage is reached, whereas, in uncropped pots the rate is of a much more uniform type. Compared with the results of the previous experiment, there is also a considerable reduction in the amount of gas given off from the uncropped pots, a result in accordance with the decrease in the amount of decomposable organic matter present.

The main point of interest, however, centres around the unmanured pots for, whether cropped or uncropped, no gas was evolved until the experiment was nearing a conclusion, and even then the volume was exceedingly small. It therefore appears justifiable to conclude that the volume of nitrogen gas produced in swamp paddy soils is dependent to a very considerable extent upon the quantity of decomposable organic matter present, a conclusion which receives considerable support in the sequel. If this is the case then the probability is that this nitrogen is derived from the organic matter which consequently is of less direct manurial value than has hitherto been considered to be the case. In this connection it must be made quite clear that the non-evolution of gas from any pot does not necessarily mean that no gas is being produced but only that there is not sufficient produced to cause it to be forced out of the soil. In fact the volume of gas held up in all paddy soils is considerable.

Considering as a whole the results obtained in these two experiments three main conclusions are to be drawn: (1) *that green manures and soil organic matter normally decompose under paddy soil conditions with the production of gaseous nitrogen, a considerable proportion of which ultimately escapes from the soil;* (2) *that in uncropped soils this nitrogen escapes at a fairly uniform rate whereas the presence of a crop prevents the escape of the gas during the early stages of growth and brings about a very considerable escape in the later stages; and* (3) *that there is a further production of nitrogen gas which is dependent upon the presence of a crop.*

If these conclusions are correct it now remains

(1) to produce supplementary evidence in support of conclusion (1);

(2) to determine the manner in which the crop causes the non-evolution of gas from the soil during the early stages of growth; and

(3) to determine the source of the nitrogen gas produced through the action of the crop alone.

Further experiments were therefore instituted to determine, if possible, these points.

THE CAUSE OF THE RETARDATION IN THE RATE OF GASEOUS EVOLUTION.

In a previous memoir attention was drawn to the fact that the amount of gas escaping from cropped soils during the early stages of growth was comparatively small, whereas, during the later stages the position was reversed, but apart from drawing attention to the fact it was found impossible to offer a satisfactory explanation. This fact is now confirmed by the results of the experiments which have now been considered.

The cause of the phenomenon may be biological in character in that the crop may so affect the biological activities of the soil as to actually retard, if not even altogether change, the normal course of the decomposition of the organic matter present. There may also be during the earlier stages of growth such an absorption of nitrogenous substances by the crop as to materially lessen the normal gas production.

Apart from probable biological causes there is a possible one of a purely physical character. These paddy soils are of a very heavy type and are characterized by the large proportion of the finest grades of soil particles they contain. This being the case it is possible that the fine roots of the crop, which normally are found mainly in close proximity to the surface of the soil, would, in conjunction with the fine soil, form a layer offering a much greater resistance to the passage of the gases than would be the case in uncropped soils. In these circumstances, the gaseous products of the fermentation would be held up in the soil for a longer period and an apparent retardation of the fermentation produced.

To decide between the merits of these theories the following experiments were instituted. If the physical theory were correct then by using a coarse soil, the escape of the gas would be facilitated and the phenomenon of retardation during the early stages of the growth of the crop would become less prominent or even entirely disappear. On the other hand, if this coarse soil consisted of a mixture of sand and paddy soil the biological relationships would not be materially altered and if these were the determining factors the phenomenon would persist under the new conditions.

In carrying out these experiments the soil used in the pot cultures consisted of a mixture of four parts of clean river sand and one part of paddy soil obtained in a perfectly fresh condition from the fields of the Agricultural College, Coimbatore. Apart from this the experiments were merely replicas of the ones previously discussed and so call for no further comment. The results obtained are as follows :—

TABLE III.

Showing evolution of Nitrogen and Methane from mixture of sand and fresh soil.

A. MANURED POTS.

Days collecting gas	Cropped Pot I				Cropped Pot II				Uncropped Pot			
	Nitrogen		*Methane*		*Nitrogen*		*Methane*		*Nitrogen*		*Methane*	
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate
1st to 14th day ...	6·7	0·48	nil	nil	7·3	0·52	nil	nil	11·6	0·41	1·0	0·04
14th to 28th ,, ...	23·1	1·65	0·9	0·06	38·1	2·72	1·4	0·10				
28th to 42nd ,, ...	19·6	1·40	nil	nil	23·3	1·74	nil	nil	4·5	0·32	nil	nil
42nd to 56th ,, ...	22·2	1·58	0·3	0·02	18·3	1·31	nil	nil	6·1	0·44	nil	nil
56th to 70th ,, ...	32·8	2·34	5·0	0·36	23·1	1·65	nil	nil	7·8	0·56	0·3	0·02
70th to 84th ,, ...	41·5	2·96	10·1	0·72	45·2	3·22	4·3	0 31	5·8	0·41	nil	nil
84th to 97th ,, ...	60·4	4·65	16·4	1·26	40·5	3·11	10·1	0·78	4·2	0·32	0·4	0·03
97th to 105th ,, ...	42·8	5·35	17·7	2·21	31·6	3·95	11·3	1·41	4·2	0·32	0·1	0 01
105th to 110th ,, ...	30·9	6·18	19·5	3·90	22·5	4·50	12·0	2·40				
Totals and averages ...	280·9	2·54	69·9	0·63	249·9	2·35	39·1	0·35	41·2	0·40	1·8	0·01

B. UNMANURED POTS.

1st to 14th day ...	4·6	0·33	nil	nil	5 0	0·36	nil	nil	7·8	0 28	nil	nil
14th to 28th ,, ...	7·5	0·54	0·2	0·01	7·8	0·56	nil	nil				
28th to 42nd ,, ...	11·9	0·85	0·4	0·03	10·3	0·74	0·3	0·02	2·8	0 20	nil	nil
42nd to 56th ,, ...	12·0	0·86	nil	nil	10·5	0·75	nil	nil	1·7	0·12	nil	nil
56th to 70th ,, ...	13·3	0·95	nil	nil	11·7	0·84	nil	nil	1·1	0·08	nil	nil
70th to 84th ,, ...	10·7	0·77	0·7	0·05	11·9	0·85	0·5	0·04	0·9	0·06	nil	nil
84th to 97th ,,	13·4	1·03	1·7	0·13	12·1	0·98	1·0	0·07	3·5	0 27	nil	nil
97th to 108th ,, ...	12·6	1·14	3·1	0·28	12·0	1·09	2·0	0·18	2·8	0·25	nil	nil
Totals and averages ...	86 0	0·80	6·1	0·05	81·3	0·75	3·8	0 03	20·6	0·19	nil	nil

A comparison of these results with those detailed in the preceding section of this memoir distinctly points to the occurrence of a different sequence of events. The phenomenon of the non-evolution of gas in the early stages of growth has disappeared and in its place there is a greater evolution of gas from the cropped pots than from the uncropped pots throughout the whole course of experiment. At the same time the irregularity previously noticed with regard to the unmanured pots, in that less total gas is given off from the cropped than from the uncropped pots has vanished, and they fall into line with the manured pots. (See Charts V and VI.) From this it is concluded that similar factors are at play whether the soil is manured or not, but the fact that much more gas is evolved from manured than from unmanured pots shows that the intensity of the action is largely dependent upon the amount of easily decomposable organic matter present.

It is also noteworthy that, whereas the rate of evolution of nitrogen from uncropped pots is fairly uniform that from cropped pots shows, in general, an increasing rate with the age of the crop. This fact serves to emphasize the conclusion previously drawn that there is a considerable evolution of nitrogen due to the presence of a crop and which is independent of the presence of organic matter in the soil or manure.

The main result of this experiment has been, however, to clearly demonstrate that the non-evolution of gas in the early stages of the growth of the crop under natural conditions is mainly a purely physical phenomenon and not a biological one. It is due to superficial root development of paddy acting in conjunction with the very fine textured soils and thus forming a surface layer which offers greater resistance to the passage of the gases than occurs in uncropped soils. These gases are thus trapped beneath the surface of the soil and the phenomenon of retarded evolution of gas is produced. This is in agreement with field observations, for, in uncropped soils the gases are fairly evenly distributed throughout the soil, whereas, in cropped soils the main accumulation of gas is always found in those areas which contain the roots of the crop, and comparatively little is found in any bare patches.

This trapping of the soil gases in close proximity to the organized surface film is one more factor leading to their more complete utilization for the aeration of the roots and at the same time it offers a very simple explanation of that curious change in composition of the soil gases under the action of a crop which has been referred to in a previous publication. These points will be fully discussed in the sequel.

In this experiment fresh soil was used which introduced a quantity of organic matter apart from that contained in the green manure added.

CHART V. Showing total evolution of Nitrogen to date from a mixture of sand and fresh Paddy soil.

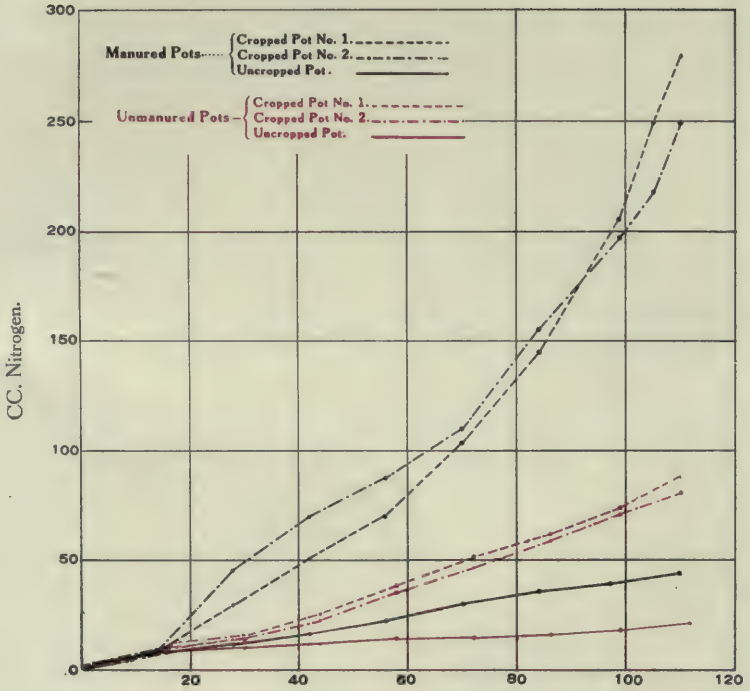


CHART VI. Showing variations in rate of Nitrogen evolution from mixture of sand and fresh soil.

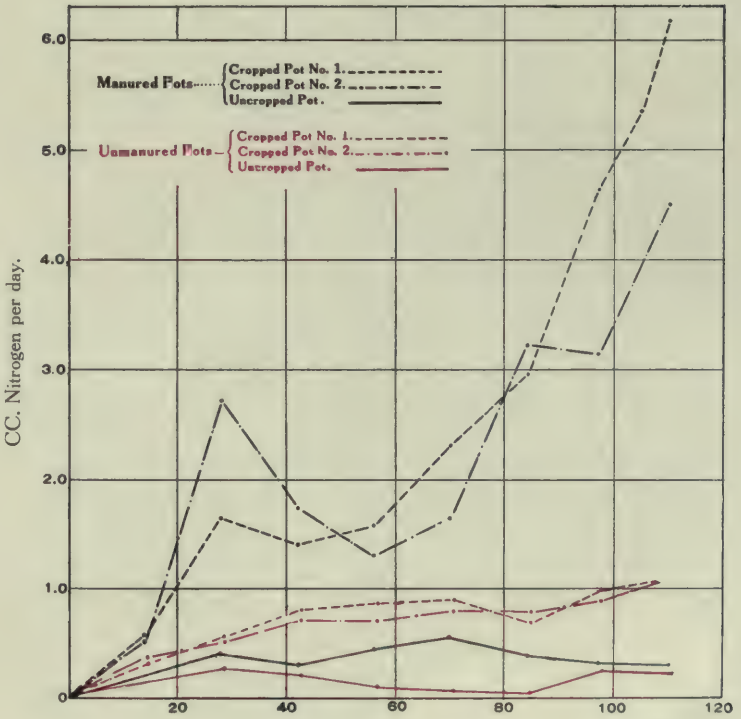


CHART VII. Showing total evolution of Nitrogen to date from mixtures of sand and stored soil.

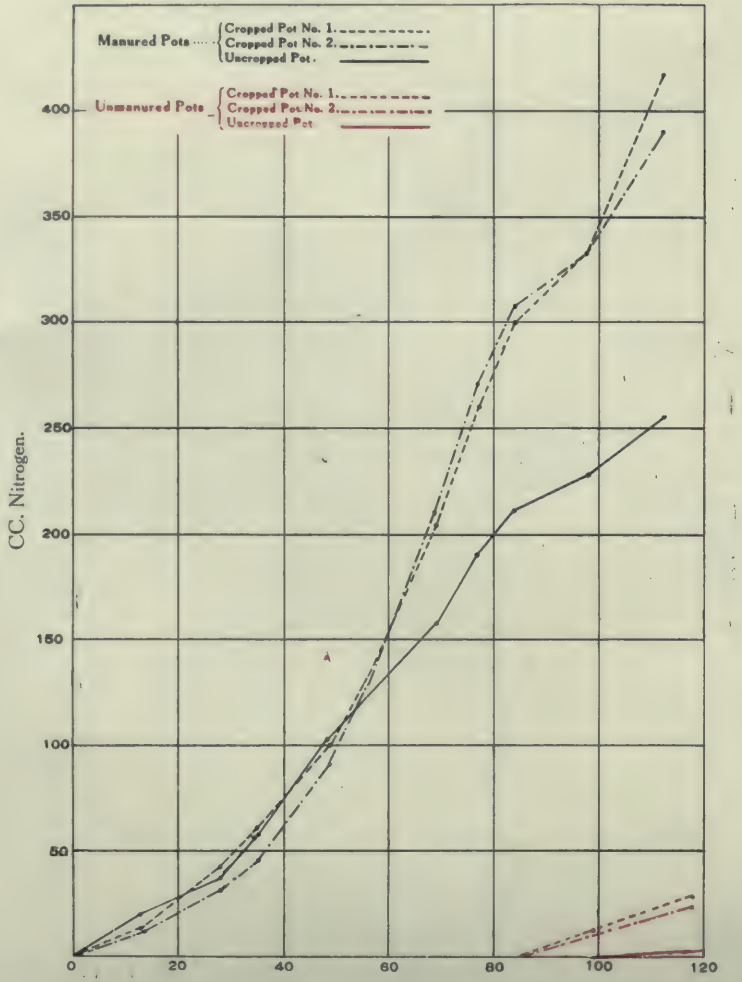
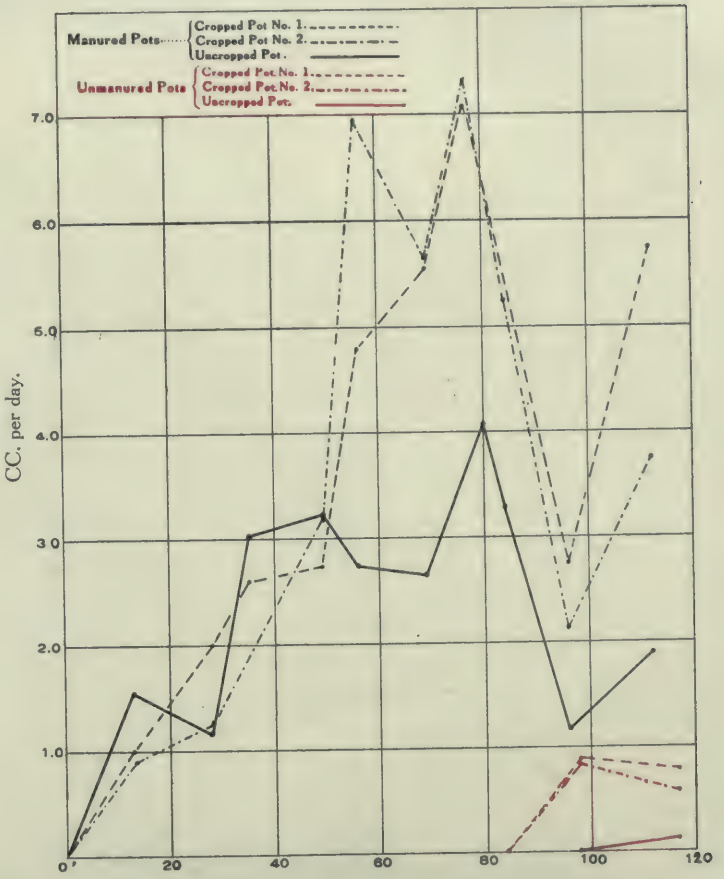


CHART VIII. Showing variations in the rates of Nitrogen evolution from mixtures of sand and stored soil.



Following the same line of argument adopted in the preceding section it was deemed advisable to repeat this experiment using a mixture of sand and stored soil, thus reducing the amount of decomposable organic matter present to that introduced solely by the green manure. It was thus hoped to obtain clearer evidence regarding the relationship between the amount of organic matter present in the soil and the quantity of nitrogen evolved. There was also a probability that the action of the crop in bringing about a nitrogen evolution would also be made more prominent.

Apart from the use of stored soil this experiment only differed from the preceding one in the employment of a strain of pure seed. The results are given in Table IV and the corresponding curves in Charts VII and VIII.

This experiment serves to emphasize the conclusion previously drawn that the retardation of the normal rate of gas evolution is chiefly due to physical causes and not biological ones. In addition it demonstrates the fact that in soils containing little organic matter there is no evolution of nitrogen until the later stages, when the influence of the crop becomes most apparent. In the manured pots the nitrogen evolution is practically the same from cropped or uncropped ones, until the crop has reached half growth, and then there is an increased rate of evolution from the cropped pots only. It may be concluded from this that the crop has little influence upon the course of the normal decomposition of organic matter in these soils and consequently the greatly increased output of nitrogen gas from cropped soils is largely due to the crop itself.

Taking this series of experiments as a whole the conclusions brought out are :—

1. *That organic matter when decomposing in these soils liberates considerable quantities of nitrogen gas and that this decomposition is not materially modified by the presence of a crop.*

2. *That the crop in some way or another is connected with the production of a further quantity of nitrogen and methane and that this factor is most prominent during the later stages of growth.*

3. *That the non-evolution of gas from cropped soils during the early stages of growth and under normal conditions is a purely physical phenomenon and not a biological one, and is due to the surface development of the roots forming, in conjunction with the fine textured soil, a layer offering increased resistance to the passage of the gases.*

TABLE IV.

Showing evolution of Nitrogen and Methane from mixtures of sand and stored soils.

A. MANURED POTS.

Dates of Collection	CROPPED POT I				CROPPED POT II				UNCROPPED POT			
	N		CH_4		N		CH_4		N		CH_4	
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate
1st to 13th day ...	12·8	0·99	nil	nil	12·5	0·96	0·5	0·04	20·2	1·55	9·8	0·75
13th to 28th ,, ...	29·9	1·99	3·8	0·25	19·0	1·27	1·5	0·10	17·1	1·14	17·1	1·14
28th to 35th ,, ...	18·1	2·58	6·1	0·87	14·3	2·04	2·2	0·31	21·2	3·02	23·7	3·39
35th to 49th ,, ..	38·5	2·75	8·4	0·60	44·8	3·20	7·0	0·50	45·1	3·22	42·0	3·00
49th to 56th ,, ...	33·7	4·81	16·8	2·40	48·6	6·94	15·1	2·15	19·3	2·75	18·8	2·68
56th to 69th ,, ..	72·2	5·55	27·2	2·09	73·5	5·65	16·7	1·28	34·6	2·66	17·4	1·34
69th to 77th ,, ...	56·5	7·06	26·3	3·29	59·0	7·38	21·4	2·68	32·6	4·08	7·1	0·89
77th to 84th ,, ...	37·8	5·40	23·2	3·31	36·7	5·24	12·1	1·73	23·0	3·29	11·7	1·67
84th to 98th ,, ...	38·6	2·76	16·4	1·17	29·6	2·11	4·7	0·34	16·7	1·19	11·0	0·79
98th to 112th ,, ...	80·3	5·73	26·0	1·85	52·2	3·73	12·8	0·91	26·9	1·92	12·7	0·91
Totals and averages ...	418·4	3·74	154·2	1·37	390·2	3·48	94·0	0·84	256·7	2·29	171·3	1·53

B. UNMANURED POTS.

1st to 84th day ...	...	No gas	...	...	...	No gas	...	..	...	{No gas	...	...
84th to 98th ,, ...	12·5	0·89	nil	nil	12·2	·87	nil	nil	.	{No gas	.	...
98th to 117th ,, ...	15·1	0·79	0·6	0·03	11·0	·58	nil	nil	2·6	...	nil	nil
Totals and averages ...	27·6	0·23	0·6	0·005	23·2	0·20	nil	nil	2·6	0·02	nil	nil

The Cause of the Production of Nitrogen Gas under the Action of the Crop.

The final point remaining for elucidation is the reason for the production of nitrogen gas under the action of the crop as distinct from that caused by the decomposition of the organic matter present in the soil and the green manure.

Field observations point to the solution of this lying in the fact that under normal conditions there are always found throughout the soil a large number of dead and decaying paddy roots even where the crop is in a perfectly vigorous and healthy condition. As organic matter has been shown to lead to a disengagement of nitrogen gas during the process of its decomposition in paddy soils it seems permissible to assume that the decomposition of these roots would likewise have the same effect. This assumption would also account for this factor appearing most prominent during the later stages of growth when root development has reached a maximum.

To test the theory an experiment was carried out in sand culture only, the nutrients being supplied by adding 1·5 litres of the following solution to each pot :—

6·0	grams	Ammonium phosphate.
1·8	,,	K_2SO_4
1·5	,,	$MgSO_4$
1·5	,,	NaCl.
2	drops	5% $FeCl_3$ solution.
600	cc.	water.

A further quantity equal to 6·5 litres of distilled water was also added so as to fully saturate the sand with water.

In addition 10 grams of calcium carbonate were mixed with the sand. Although some difficulty was experienced in getting the seedlings well established, once this occurred vigorous growth ensued and the resulting crop was very much better than those obtained in the preceding experiment with mixtures of sand and soil. Under the conditions of this experiment no organic matter was present in the soil other than that produced by the development of the roots of the crop. The production of the nitrogen gas by the decomposition of green manure was thus eliminated and consequently any production of nitrogen and methane could with certainty be referred to the decomposition of the roots. Unfortunately, owing to difficulties in procuring apparatus it was found impossible to use the same sized funnel in all cases so that although one cropped pot and one uncropped pot were large in size

and held funnels twelve inches in diameter, the remaining cropped pot was somewhat smaller in size so as to accommodate a ten-inch funnel. The results obtained are therefore not strictly comparable in a quantitative sense, but they are of the same type and permit of the same conclusions being drawn.

In addition to the above an experiment was also carried out with green manure in place of ammonium sulphate. To each pot was added 80 grams *calotropis* leaves and 10 grams K_2SO_4, 10 grams pure basic super and 10 grams $CaCO_3$. This experiment was intended to give extra evidence in favour of the physical retention of the gases under normal conditions, but mainly to help in forming a decision regarding the period during which the gas evolution due solely to crop chiefly occurs. The results obtained, however, did not fulfil expectations owing to the very poor crop raised. The results of both experiments are given in Table V and the corresponding curves in Charts IX and X.

CHART IX. Showing total evolution of Nitrogen to date from the sand cultures.

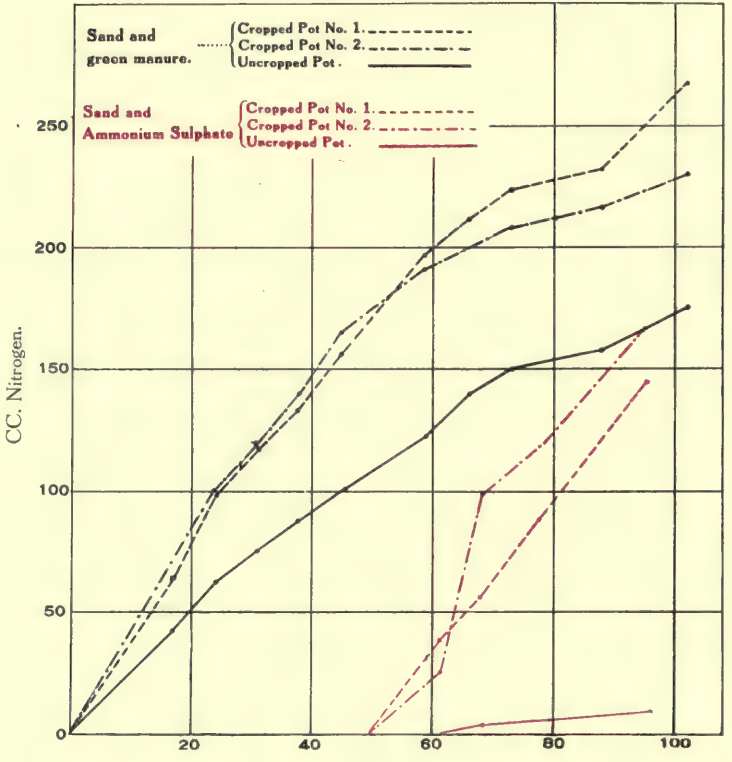


CHART X. Showing variations in the rate of Nitrogen evolution from the sand cultures.

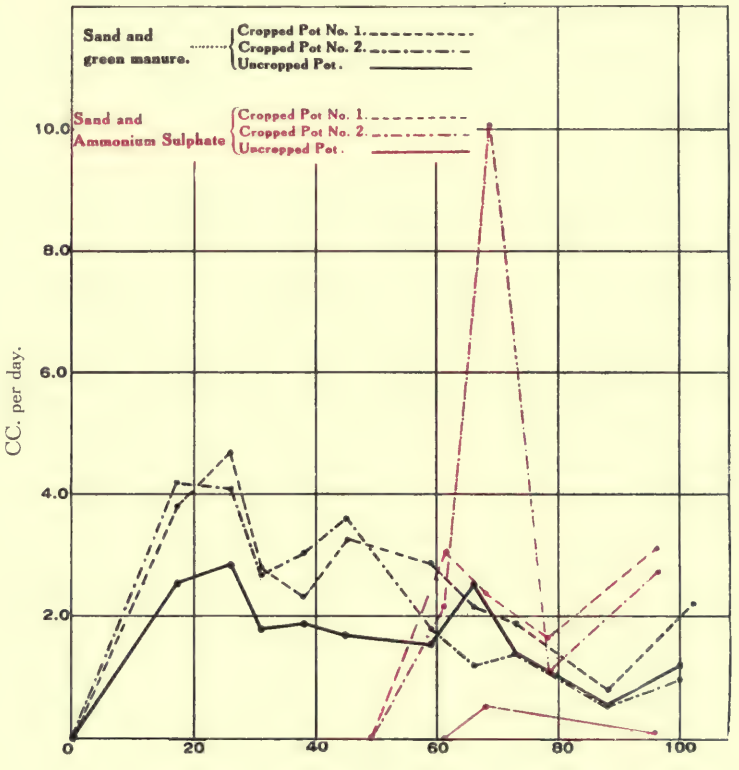


TABLE V.

Showing evolution of Nitrogen and Methane in sand cultures.

A. SAND AND GREEN MANURE.

No. of days collecting	CROPPED POT I				CROPPED POT II				UNCROPPED POT			
	N		CH_4		N		CH_4		N		CH_4	
	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate	cc. collected	Daily rate
1st to 17th day ...	64·2	3·78	25·6	1·50	71·5	4·21	42·3	2·49	43·0	2·53	23·6	1·39
17th ,, 24th ,, ...	33·1	4·73	17·5	2·50	28·4	4·06	27·7	3·95	19·9	2·84	19 6	2·80
24th ,, 31st ,, ...	19·9	2·84	7·2	1·03	18·7	2·67	9·9	1·41	12·5	1·79	12·5	1·79
31st ,, 38th ,, ...	16·1	2·30	4·8	0·68	21·4	3·05	8·9	1·27	13·1	1·87	13·0	1·85
38th ,, 45th ,, ...	22·9	3·27	8·3	1·18	25·3	3·61	10·1	1·44	12·0	1·71	9·2	1·31
45th ,, 59th ,, ...	40·1	2·86	nil	nil	25·0	1·79	2·3	0·16	22·0	1·57	23·9	1·71
59th ,, 66th ,, ..	15·1	2·15	3·4	0·48	8·4	1·20	3·1	0·44	17·8	2·54	10·3	1·47
66th ,, 73rd ,, ...	12·9	1·84	2·4	0·34	9·4	1·34	2·8	0·40	9·7	1·38	7·1	1·01
73rd ,, 88th ,, ..	12·2	0·81	1·7	0·11	7·9	0·53	1·0	0·07	7·9	0·53	5·5	0·37
88th ,, 102nd ,. ..	30·5	2·18	3·3	0·24	14·2	1·01	2·1	0·15	17·5	1·25	10·4	0·74
Totals and averages ...	267·0	2·62	74·2	0·73	230·2	2·26	110·2	1·08	175·4	1·72	135·1	1·32

B. SAND AND AMMONIUM SULPHATE.

1st to 50th day ...	...	No gas	...	...	...	No gas	..	...	...	No gas	...	...
50th ,, 62nd ,, ...	38·9	3·24	4·1	0·34	25·1	2·09	nil	nil	...	No gas	...	...
62nd ,, 69th ,, ...	16·4	2·34	2·9	0·41	70·6	10·08	0·7	0·1	3·9	0·55	nil	...
69th ,, 79th ,, ...	31·9	1·68	4·4	0·23	20·0	1·05	nil	nil				
79th ,, 97th ,, ..	56·6	3·14	6·3	0·35	49·8	2·76	2·7	·15	2·8	0·08	nil	..
Totals and averages ...	143·8	1·48	17·7	0·18	165·5	1·70	3·4	0·03	6·7	0·07	nil	nil

The result of the experiment with sand and purely mineral manures shows clearly the cause of the disengagement of nitrogen gas under the influence of the crop. The production of the gas in the uncropped pot is practically *nil* showing that there is no appreciable formation of nitrogen gas when organic matter is entirely absent and that the comparatively large evolution of nitrogen from the corresponding cropped pots is solely due to the influence of the crop. The gas collected from the latter is associated with methane, which could only be produced through the fermentation of organic matter, and as the only organic matter present in the soil of these pots consists of the roots of the crop it appears obvious that this disengagement of gaseous nitrogen under the influence of the crop is directly associated with the destruction of, at least, some of the roots. It is also a matter of general field observation that the paddy plant is continually putting out new roots and that many of the older roots are in a state of decay and consequently it is permissible to conclude that *a considerable proportion of the nitrogen gas which escapes from the soil of cropped paddy soils is liberated through the decomposition of some of the roots of the crop and has no connection with the decomposition of green manures or of soil organic matter.* The fact that gas was only obtained from these pots towards the final stages of the experiment also leads to the further conclusion that this phenomenon is most prominent during the later stages of growth.

Additional evidence that root decomposition is responsible for nitrogen evolution is obtained by collecting the gas from pots after the crop has been harvested. Very considerable volumes of both nitrogen and methane are obtained from cropped pots, whether manured or unmanured, whereas, the uncropped pots maintained a low rate of evolution. Here the production of nitrogen gas can only be due to root decomposition. The following table illustrates this point :—

TABLE VI.

Showing evolution of Nitrogen after the harvest has been taken.

	Nitrogen collected during growing season			Nitrogen collected after harvest		
	Number of days	Volume collected	Rate	Number of days	Volume collected	Rate
		cc.	cc.		cc.	cc.
Cropped and manured Pot I ..	153	225·7	1·42	24	101·7	4·2
Cropped and manured Pot II ...	153	251·0	1 64	24	130·7	5·4
Manured and uncropped .	153	134·4	0·88	24	8·2	0·34
Cropped and unmanured Pot I ...	159	88 5	0·56	23	90·0	3 9
Cropped and unmanured Pot II ..	159	74·7	0·47	19	45·4	2·4
Unmanured and uncropped ..	159	104·9	0 66	23	3·1	0·13

Turning now to the pots containing sand and green manure it must be borne clearly in mind that the crop produced was exceedingly poor being, in fact, only about one-tenth of that obtained from pots containing soil and green manure and one-eighth that from a similar pot containing sand and ammonium sulphate only. This being the case the effect of the crop is reduced to a minimum in this experiment and a comparison of the data obtained from the cropped and the uncropped pots should yield more nearly equal values than in the cases previously considered where the cropping is much better. The results obtained show this to be the case and consequently this experiment is mainly concerned with the production of nitrogen gas through the decomposition of green manure and soil organic matter.

That the nitrogen in this case is mainly derived from the organic matter present is shown by comparing the results with those from the sand and ammonium sulphate series. Further, as the greater portion of this nitrogen is given off during the earlier stages of the experiment, it may be concluded that this phenomenon is most prominent during the earlier portion of the cropping season.

This experiment with sand and green manure thus emphasizes the conclusion previously arrived at that *a considerable proportion of the nitrogen gas which escapes from paddy soils is produced through the fermentation of green manure or soil organic matter.*

General Summary and Discussion of Results.

I. It has been demonstrated that a very considerable proportion of the gaseous nitrogen normally found in swamp paddy soils is produced through the decomposition of organic matter, a view which is supported by Leather's estimate of the nitrogen-argon ratio of these gases.[1]

The nitrogen gas thus liberated is derived from two distinct sources, namely, (*a*) from the decomposable organic matter of the soil or of the green manure used, and (*b*) from a certain proportion of the roots of the crop which die and subsequently decompose.

The production of gaseous nitrogen from soil organic matter and green manure persists throughout the growing season, but is most prominent during the earlier period, whereas, that derived from root decomposition is most prominent during the later stages of growth and persists after harvest time.

II. There is no evidence forthcoming to show that the crop interferes with, or materially alters, the normal course of the fermentation of the soil

[1] Leather, J. W. Soil Gases. *Mem. Dept. Agri, India, Chem. Ser.* vol. IV. no. 3, p. 113.

organic matter and green manure, in fact the balance of evidence is distinctly against this theory.

III. Under normal conditions in uncropped soils the nitrogen gas thus produced escapes from the soil into the air at a fairly uniform rate. On the other hand, that produced in cropped soils does not escape in any quantity until about the time when the plant is running up for flower. At this stage a very marked escape of gas occurs which continues up to and past harvest time.

This irregularity in the escape of the soil gases from cropped paddy soils is a purely physical phenomenon, and is caused by the roots of the crop forming, in conjunction with fine soil, a surface layer which resists the passage of the gases. The gas is thus trapped and retained in the soil until the accumulation is sufficient to cause a passage to be forced, or until the decay of some of the roots opens out such a passage.

IV. In a previous publication attention has been called to the curious change in the composition of the soil gases under the action of a paddy crop. It has been shown that the composition remains fairly uniform in uncropped soils and that methane is present in a much larger proportion than the nitrogen. This is also the case in cropped soils up to about thirty days after transplanting, but after this stage a rapid change occurs which results in the nitrogen predominating, and this continues up to harvest time. No reasonable explanation has been available hitherto to account for this change, but the facts now brought forward throw a new light on the phenomenon and co-ordinate it with the previous work relating to the utilization of the soil gases for the aeration of the roots of the crop.

In these poorly drained soils a very large proportion of the roots of the paddy are either on, or in very close proximity to, the surface of the soil, and, as it has been pointed out, they prevent the soil gases from escaping readily into the air. The effect of thus trapping the gases is to concentrate them in the soil in very close proximity to the organised surface film, which has been shown to possess the power of oxidizing methane and hydrogen to carbon dioxide and water, and also to decompose the carbon dioxide thus produced with the liberation of pure oxygen. The oxygen thus produced is then available for the aeration of the roots.

The gases present in freshly manured and puddled soils contain about 70 per cent. of methane and 30 per cent. of nitrogen which readily escapes from uncropped soil. If this also occurred in cropped soils during the early stages of growth, when the demand for the root aeration is relatively small,

there would subsequently ensue a considerable reduction in the efficiency of the root aeration. This, however, is not the case and *the action of the roots in retarding the escape of the soil gases conserves the methane and thus makes it available for the later stages of growth when the plant is more mature and the demand for root aeration greater.* This action of the roots of the crop may, therefore, be looked upon as a natural provision for the conservation of methane.

Further, the gases thus imprisoned are held in close proximity to the surface film and consequently diffusion of the methane and its subsequent oxidation will slowly occur. As the irrigation water entering the soil already contains in solution a considerable amount of nitrogen, there will not be the same tendency for this gas to diffuse as is the case with methane, and therefore the sequence of events will be for methane to gradually disappear and the nitrogen to accumulate, so that in time the latter gas will preponderate. The result will be that a change in composition of the soil gases will occur such as has been shown to take place in cropped soils. In uncropped soils, on the other hand, the escape of the soil gases is not retarded and the nitrogen and methane will reach the surface film together and the former escape ; thus the composition of the soil gases will not materially alter.

The physical retention of the soil gases through the action of the roots of the crop, taken in conjunction with the oxidizing action of the film, offers a simple and complete explanation of the change in composition of the soil gases under the action of the crop.

Further evidence in support of the above is adduced from the fact that hydrogen, one oxidizable constituent of the soil gases in uncropped soils, is practically non-existent in cropped soil gases, just as the methane, the other oxidizable constituent of the soil gases, is reduced in proportion.

V. The liberation of nitrogen gas owing to the decay of some of the roots is no doubt due to some extent to the decomposition of the nitrogenous organic matter contained in them under swamp soil conditions, but whether or not the source of the whole of the nitrogen thus produced can be ascribed to this cause is a debatable point. The older portions of paddy roots contain a certain amount of gas which would escape when the roots decay, and it, therefore, seems very probable that some of the nitrogen liberated under the action of the crop may have an atmospheric source. Some support is given to this from Leather's analyses of paddy soil gases by which he demonstrated the presence of argon in them. The nitrogen-argon ratio obtained was small, much smaller in fact than the ratio required on the assumption that the nitrogen was derived from the atmospheric gases dissolved in the irrigation

water, but nevertheless the presence of this small amount of argon argues the source of a certain proportion of the nitrogen as being the atmosphere.

VI. The results obtained in these series of experiments clearly show that a considerable amount of the nitrogen contained in green manure is liberated in the gaseous form and so made useless so far as the feeding of the crop is concerned. At the same time, the fact that a crop of inferior value can be raised in sand culture through the agency of these manures shows that they have a certain direct value, but, even after making full allowance for this, it is evident that this value is very low and consequently the undoubted benefit derived from using these manures in certain types of soil must be ascribed mainly to their indirect manurial properties.

Definite evidence regarding the direct manurial value of green manures is not easy to obtain owing to the difficulty experienced in rendering their indirect action inoperative, without, at the same time, affecting relative cropping values. Thus copper sulphate has been used in these experiments to inhibit the action of the surface film and, the effect has been to inhibit the indirect effect of green manures in promoting root aeration. Nevertheless, a comparison between the cropping of pots treated with copper sulphate and similar untreated ones is rendered valueless by the fact that copper acts as a plant stimulant. In fact treated pots generally yield better crops than untreated pots. When, however, the formation of oxygen by the surface film is inhibited by preventing the access of light to it, it is found that crops from manured pots under normal conditions were on the average about 37 per cent. better than the darkened pots. The experimental results on which this comparison is based are given in the following table :—

TABLE VII.

Particulars of experiment	Wt. of grain in grams	Wt. of straw and chaff in grams	Total yield
Normal plant No. 1	7·95	22·75	30·70
,, No. 2	6·13	19·00	25·13
,, No. 3	9·55	17·47	27·02
Average of normal plants ..	7·87	19 74	27·61
Darkened pot No. 1	4·12	13·17	17·29
,, No. 2	7·55	13·00	20·55
,, No. 3 .. .	5·60	12·30	17·90
Average of darkened pots ..	5·75	12·82	18·58

4
3
2
1

In this experiment the method of darkening the surface was to cover the pot with a tin lid through which a hole was pierced to allow for the passage of the plant, and this hole was plugged with cotton wool so as to exclude any light. Care was also taken to conduct any tillers produced through the hole so that the green part of the plant was exposed to the light and only the organized film on the soil kept in the dark. The experiment was only a preliminary one and crude in type, but if this difference in cropping is ascribed to differences in root aeration then the indirect value of green manures must be considerably greater than the direct one. Further experiments of a similar type are being carried out.

A certain amount of indirect evidence with regard to this point is, however, available from a comparison of the crops raised under varying conditions of our experiments. The Plate opposite gives a photograph of the crops referred to :—

Pot I is the crop raised with sand and ammonium sulphate, Pot II with sand and green manure, Pot III with a mixture of sand and soil and green manure, and Pot IV with paddy soil and green manure. In all cases the seedlings were from the same seeds and raised at the same time, and all the pots were treated with copper sulphate solution, so that the indirect action of the green manure in increasing the root aeration is eliminated and the stimulative effect of the copper may be assumed to apply proportionately to all the crops. The pots, however, are not the same size and consequently the actual cropping values are not comparable, but the amount of green manure and the number of seedlings in each pot is proportional to the weight of the contents (except No. I which contains no green manure) so that a good idea of the relative cropping values can be obtained from the photo.

It is evident that the crop obtained with a mixture of sand and soil is much inferior to that obtained from soil alone, and again, that obtained with sand alone is in a similar way inferior to that from a mixture of sand and soil. The proportion of green manure to the contents of the pots and also to the number of seedlings present is the same, and it contains enough nitrogen to satisfy the needs of the crop, but, notwithstanding this, there is a diminishing output. The only factor which diminishes in value in a similar way is the proportion of paddy soil, and, consequently, it must be concluded that the direct manurial value of green manures is small and that the paddy crop is mainly dependent upon the soil nitrogen for its support.

If in addition it is borne in mind that easily decomposable soil organic matter undergoes rapid fermentation in these soils with the liberation of some of its nitrogen, then it would appear probable that the paddy crop is mainly

dependent upon that portion of the soil nitrogen which is in a more or less mineralized condition. This conclusion is supported by the cropping of Pot No. 1, containing nitrogen in the form of ammonium sulphate only, which is almost as good as that of Pot No. 4 and very much better than Pots Nos. 2 and 3.

It may be argued against this conclusion that the addition of sand to the soil has altered the mechanical texture of the soil and that, as swamp paddy is habituated to exceedingly fine soils, this has unfavourably affected the cropping. This objection is negatived by the fact that it is possible to raise a good crop in sand culture only.

Another objection which may be raised is that by reducing the proportion of soil the toxic effect of decomposing green manure is intensified with baneful effect on the crop. Against this is argued the fact that manured pots of soil, or of mixtures of sand and soil, yielded better results than the corresponding unmanured pots.

Considering carefully the whole of the facts which have been collected regarding the relationship of green manures to the soil and crop, the only feasible conclusion which can be drawn is that the nitrogen of these manures has little actual manurial value, that the crop is mainly dependent upon soil nitrogen for its support, and that green manures owe the efficiency mainly to their indirect action on the soil and by increasing root aeration.

VII. In view of the conclusions thus arrived at it becomes necessary to consider carefully the whole subject of green-manuring paddy soils in order to evolve possible methods of application, or even of cultivation, which would lead to improved cropping results being obtained.

Hitherto, when experiments have been formulated for the purpose of obtaining the relative value of green manures (this must apply to some extent also to bulky organic manures of the type of oil cakes) it has been customary to base them upon the nitrogen content, or in other words, upon their direct manurial value. Comparisons of this type when instituted between different organic manures may yield valuable results as the functions performed are the same, but, between mineral and organic manures no such comparisons can be made, because, so long as cultural conditions remain as at present, the former are mainly direct acting manures and the latter are now shown to be chiefly indirect in type. In fact these two types of manures can be said to be members of complementary classes so far as paddy cultivation is concerned.

Further, the facts that swamp conditions are maintained throughout the whole growing season, and that under these conditions the nitrogen contained in organic manures is liberated in the gaseous form and thus made useless so far as the crop is concerned, indicate the impossibility of utilizing to the fullest extent both the indirect and direct values of green manures without some material and drastic alteration in the present practice. Nevertheless, the green manuring of paddy as practised in South India has yielded exceedingly good results in past years and the use of these manures is rapidly extending, as is witnessed by the rapidly increasing demand for seed of suitable crops such as wild indigo, but occasionally the results have been disappointing, and even retrograde, so that indiscriminate general advice to use them cannot be given. This uncertainty of reaction must be ascribed to the fact that these manures owe their efficiency to their indirect action.

The general statement that green manures are very effective for paddy may, however, be accepted and consequently the problem of utilizing them to the best advantage would seem to follow two distinct lines of enquiry, namely, (1) the institution of cultural methods which would result in the nitrogen they contain being rendered useful, and (2) to accept, in a broad way, the present conditions as being unchangeable, thus utilizing only the indirect value and to aim at feeding the crop by means of suitable direct manures.

With regard to the first line of enquiry the main difficulty to be faced in attempting to make the nitrogen directly available for the crop is in regard to the ordinary methods of cultivation. During the whole of the growing season the soil is saturated with water and is under anaerobic conditions, so that the nitrogen contained in any decomposable organic matter which may be present is mainly liberated in the gaseous form and thereby rendered valueless. If, therefore, this nitrogen is to be utilized two alternatives are open, either to greatly modify, or eliminate, the methods of swamp cultivation, or to apply the manure at such a time and under such conditions that the nitrogen can become an integral component of the soil before the irrigation season commences.

The first alternative raises issues which are so involved and aims at such radical changes in the present accepted conditions that it can be eliminated from the scope of this enquiry as not being feasible in the immediate future.

The second method is more feasible in that it would not interfere seriously with the ordinary methods of paddy cultivation, but it is obvious that this cannot be attained by applying the manures when swamp conditions are prominent. In addition it is necessary that the application should be made

under conditions which will permit of the organic matter becoming more or less mineralised, otherwise, when the cultivation season arrives and swamp conditions are attained, the organic matter will decompose and the nitrogen be lost. The nitrogen, in fact, must have formed a constituent of the soil before its loss can be obviated. In other words in order to utilize the nitrogen of green manures the primary object to be aimed at should be to feed the soil rather than the crop.

It is difficult to indicate how this desideratum can be arrived at, particularly as the irrigation problem interferes considerably with any proposals to grow green crops out of season. Still, for instance, in double crop land, *i.e.*, land on which two consecutive crops are raised under irrigation followed by a dry off-season, it may be feasible to sacrifice the second crop on a portion of the land to grow a green manure crop. This crop could then be distributed over the whole at the end of the cropping season and worked in, so that decomposition would occur when the soil was drying, and therefore under more aerobic conditions, with the formation of stable soil nitrogen utilizable by the next paddy crop.

Many schemes of wide variation having this object in view could no doubt be formulated to attain this end, but, as a rule, they would be opposed to general cultural practices, and may even in themselves lead to harmful results. Generally speaking, this aspect of the case is not attractive, for it is concerned with unexplored ground, is totally opposed to the general cultural practice in South India, and would materially decrease the undoubted indirect value of these manures by leading to a destruction of carbonaceous material before the season of swamp cultivation commenced.

The second line of enquiry, which accepts the view that green manures only affect the crop in an indirect manner and do not supply food to the plant, seems to be the one which opens out the most promising field for immediate progress. From this point of view, the benefit which may accrue from applying green manures is determined by factors totally unconnected with the manure itself. A soil whose mechanical and biological characteristics, for instance, are not of a suitable type for the paddy crop, cannot benefit greatly from green manuring unless the manure itself ameliorates those conditions. In the same way the value of green manures will be approximately proportional to the intrinsic cropping value of the soil to which they are applied, for no great value can be attached to their effect on root aeration if the soil itself is incapable of raising a good crop.

These considerations account for the uncertain action of green manures when used alone and lead to the conclusion that their value goes

approximately hand-in-hand with the actual cropping value of the soil. This being the case their maximum efficiency can only be reached when other soil factors are simultaneously improved, and, of these factors, that of the manurial value of the soil is most easily affected. The most promising line of experiment would be to find a suitable system of manuring which would employ green manures in conjunction with mineral manures.

Generally speaking, paddy soils in South India are deficient in phosphates and nitrogen, and of these the former is easily made good by the use of bone-meal, superphosphate, etc. With regard to the latter the position is simple, for any improvement of the cropping, by the direct supply of nitrogen, must be brought about by the use of manures which will answer certain requirements. They must (*a*) contain no decomposable organic nitrogen compounds, (*b*) the nitrogen must be in a form assimilable by the crop, and (*c*) be retained by soil and not liable to be leached out. The first condition throws at once all the bulky organic manures out of court and leaves the choice open to the limited class of artificial nitrogenous mineral manures. Of these, nitrates are unsuited owing to the facts, that they are not retained by the soil and, that they readily undergo denitrification in paddy soils with the production of gaseous nitrogen and even poisonous nitrites. The only manures which answer completely all these requirements are ammonium compounds and compounds of the type of cyanamide which yield ammonia on decomposition. Both ammonia and cyanamide are excellent paddy manures and when suitably applied, yield good results. They, however, lack the indirect value of organic manures, and, in particular, they cannot increase the intensity of root aeration, so that, in order to obtain the best all round results it would appear desirable to use them in conjunction with green manures. This combination would, on the one hand, provide the requisite nitrogen for the growth of larger crops, and, on the other, produce the most favourable conditions for healthy root development. Some tentative experiments carried out recently by us support this contention.

Four pots were taken, all of the same size, and all containing the same weight of soil. One was left unmanured, the second was green manured only, the third was manured with ammonium sulphate and the fourth received both ammonium sulphate and green manure, in amount equal to that given in the second and third pots. These pots were puddled and had the same number of seedlings transplanted into them. Another series of pots were laid down containing a mixture of four parts of sand with one part of soil and to which

was added basic super and potassium sulphate. The results obtained are as follows :—

TABLE VIII.

Soil used	Manure present	Total crop in grams	Wt. of grain	Wt. of straw and chaff
Soil only	No manure ...	54·6	17·8	36·8
	Green manure	65·6	18·8	46·8
	Am_2SO_4	180·1	60·6	119·5
	Green manure and Am_2SO_4 ..	214·0	75·0	139·0
Sand and soil	No manure	15·6	5·0	10·6
	Green manure .. .	35·1	11·6	23·5
	Am_2SO_4	114·0	41·6	72·4
	Green manure and Am_2SO_4 ...	113·0	37·3	75·7

In the case of the pots containing only paddy soil, where the conditions are favourable for the utilization of the green manure for root aeration, it is apparent that the effect of the green manure is approximately proportional to the crop raised in the corresponding pots without green manure. Thus although the effect of adding ammonium sulphate has been to increase the total cropping value about 230 per cent. yet the increase due to the addition of green manure has been constant *viz.*, about 20 per cent., with soil alone and 19 per cent, when ammonium sulphate is present.

With regard to the pots containing a mixture of sand and soil, there is no trapping of the soil gases under the influence of the roots of the crop, and, consequently, the indirect value of the green manure has been greatly reduced. This is borne out by a comparison of the crops obtained from the pots containing Am_2SO_4.

The general position arrived at, therefore, is that a suitable combination of direct manures and green manures will produce the largest outturn from suitable land, thus opening out a large field for experiment. The position is, however, complicated by the uncertainty of the result to be expected from the use of green manures, and this entails a detailed and close study of the factors concerned, before definite rules can be formulated. It is quite possible, in fact, that, in extreme cases, it will be found that the use of direct manures only may yield the best results.

VIII. Finally attention must be drawn to the probable relative value of the two systems of green-manuring commonly practised in South India *i.e.*, to a comparison of the system of growing a green crop on the soil to which it is to

be applied with that of manuring with green leaf or a green crop brought from an external source.

The green crop usually grown in paddy soils is leguminous in character and obtains a proportion of its nitrogen from the atmosphere ; but this proportion is undetermined and, at least in the richer type of these heavy soils which are fairly well supplied with nitrogen, it would appear probable that the major portion is derived directly from the soil. In the case of non-leguminous crops the whole of the nitrogen would be taken from the soil. When the green crop is puddled into the soil decomposition occurs and most of the nitrogen contained in it is dissipated as nitrogen gas and becomes valueless from the manurial point of view. Consequently the practice of growing green crops in the paddy soil to which they are to be applied tends to deplete the store of soil nitrogen and to lead to reduced cropping so that the practice of bringing in the green manure from external sources would appear to be preferable.

This conclusion appears to be warranted by the facts now available, but it is possibly of too general a character and probably would only apply to the richer types of soil. It remains however an important aspect of the problem of paddy manuring and one which is worthy of close study.

COIMBATORE,
January, 1916.

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